Applications of genetic algorithms on fully-autonomous road networks

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My Topic

- Semi-autonomous vehicles are becoming more prevalent
- Roads are becoming more congested with a 78% increase in motor traffic since 1993 [3]
- Fully autonomous vehicle trials have been legal in parts of the US since 2015[1], with the UK set to follow by next year (2021)[7]
- Much of the current research into autonomous vehicle routing focuses on environments where human drivers are still present
- By removing the human element and working on theoretical *fully autonomous road networks* we can make many useful assumptions about the behaviour of other vehicles
- The solution to road congestion is not to build bigger roads, it is to optimise the traffic flows.
- Just 78.2% of journeys on the UK Highway Agencies roads were *on time* in the year ending June 2014 [6]

- Huge undertaking to overhaul the existing motorway network even with a relatively small network such as that of the UK
- Such a system would require a government mandate projecting decades into the future
  - e.g. All vehicles produced by 2035 will need to adhere to a universal routing standard.
  - All car manufacturers would need to have the ability to produce fully autonomous vehicles & have a standard sensor array.
- Other problems that would need to be addressed include:
  - Integrating priority-based routing to allow for emergency services to have a higher preference when routing vehicles

- From a technical perspective, there are many things that need to be implemented to make such a system possible.
  - The encoding of routes into a real-valued string of genes
  - The decoding of a real-valued string of genes to a route which a vehicle can take
  - The implementation of a function to determine the fitness of an individual route.
  - Implementation of genetic operators: Selection, crossover and mutation.
  - Cleanup operators to make certain any new individuals are valid

Literature Review

I am currently intending to pursue my research assuming the absence of classical speed lanes as described by Kala and Warwick in [5].
I have chosen to focus on the applications of Genetic Algorithms on the field for 3 reasons:

1. It is a class of optimisation algorithms that I find particularly interesting
2. GAs are *probabilistically optimal and complete*, i.e given infinite time, they will always produce the global optimal solution if such a solution exists[5]
3. It is a class of algorithm that has seen relatively minimal research in my specific sub-area

- Other approaches involve *black box approaches*, such as the use of Reinforcement and deep inverse reinforcement learning by You et al.[8]
- The downside of such an approach is that it is very difficult to reason and predict the actions of the system with a high degree of certainty. The ability to assure safety of such a critical system is very important and so GAs offer a much more predictable result
- Kala and Warwick [5] proposed a system of two coordinate systems to safely represent points on the road within Cartesian space.
- In a book by Kala [4] he proposes GAs optimise Bézier curves representing the movement arc of a vehicle

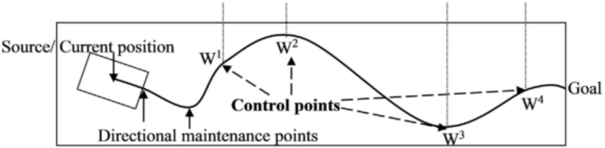

Figure: Bézier curves for route representation from Kala [4]

- A Bézier curve with n control points is said to have a *degree* of $n - 1$ (initial point is called P_0 and is not counted in degree)
- A Bézier with a degree of 1 is a straight line between the two control points (the start and end point)
- Further control points *bend* the line into a curve.
- The curve does not necessarily pass through all intermediate control points but it is determined by them.
- Bézier curves are smooth $\implies$ good for representing vehicle routes
- Trivially, they are also continuous so will represent an entire route from $A \to B$

- By their definition, Bézier curves are parametric. This lends themselves nicely to an parametric optimisation techniques such as GAs.
- We can represent the control points as genes in the genome of each candidate.
- We can represent a curve's fitness as its length within feasible space.

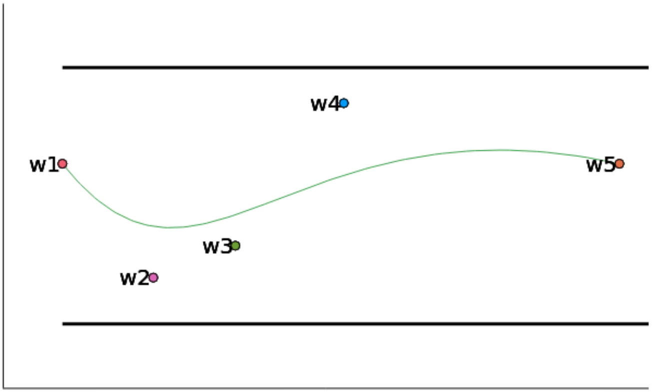

Figure: Example of Bézier curve of degree 4 in road coordinate space, my implementation

Methods

I have started by reading and collating papers, books and articles surrounding GAs and their applications on routing problems.I have found substantial research into GAs but only a few papers on my sub-area, mainly by Rahul Kala from the Indian Institute of Information Technology.
I have begun implementing various utility functions and types in Julia[2], including:

- Bézier curve functions
- Road, Individual, Phenotype and Genotype types
- plotting utilities for Roads and candidate solutions
- Population initialisation functions

Still to implement:

- Genetic operators
- Cooperative route planning wrapper

Once a basic GA has been implemented, the stage of variable and operator refinement can begin.
Here I will tweak variable values as well as implement and test various genetic operators, such as different forms of crossover

References I

[1] Autonomous Vehicles — Self-Driving Vehicles Enacted Legislation.
https://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

[2] The Julia Programming Language.
https://julialang.org/.

[3] Highways England network journey time and traffic flow data.
https://data.gov.uk/dataset/9562c512-4a0b-45ee-b6ad-afc0f99b841f/highways-england-network-journey-time-and-traffic-flow-data, June 2015.

References II

[4] R. Kala.
On-Road Intelligent Vehicles: Motion Planning for Intelligent Transportation Systems / Rahul Kala.
Butterworth-Heinemann is an imprint of Elsevier, Kidlington, Oxford, UK, 2016.

[5] R. Kala and K. Warwick.
Motion planning of autonomous vehicles in a non-autonomous vehicle environment without speed lanes.
Engineering Applications of Artificial Intelligence, 26(5):1588–1601, May 2013.

[6] I. A. roads travel time measures 020 7944 3095.
Reliability of journeys on Highways Agency roads, England: April to June 2014.
https://www.gov.uk/government/statistics/reliability-of-journeys-on-highways-agency-roads-england-apr-to-jun-2014.

References III

[7] Unknown.
UK wants fully autonomous cars on road.
BBC News, Feb. 2019.

[8] C. You, J. Lu, D. Filev, and P. Tsiotras.
Advanced planning for autonomous vehicles using reinforcement learning and deep inverse reinforcement learning.
Robotics and Autonomous Systems, 114:1–18, Apr. 2019.